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Optimal allocation of air services to the U.S. Pacific Surface Forces

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THESIS

**OPTIMAL ALLOCATION
OF AIR SERVICES TO THE
U.S. PACIFIC SURFACE FORCES**

by

P. Thomas Druggan

September 1995

Thesis Advisor: Gerald G. Brown

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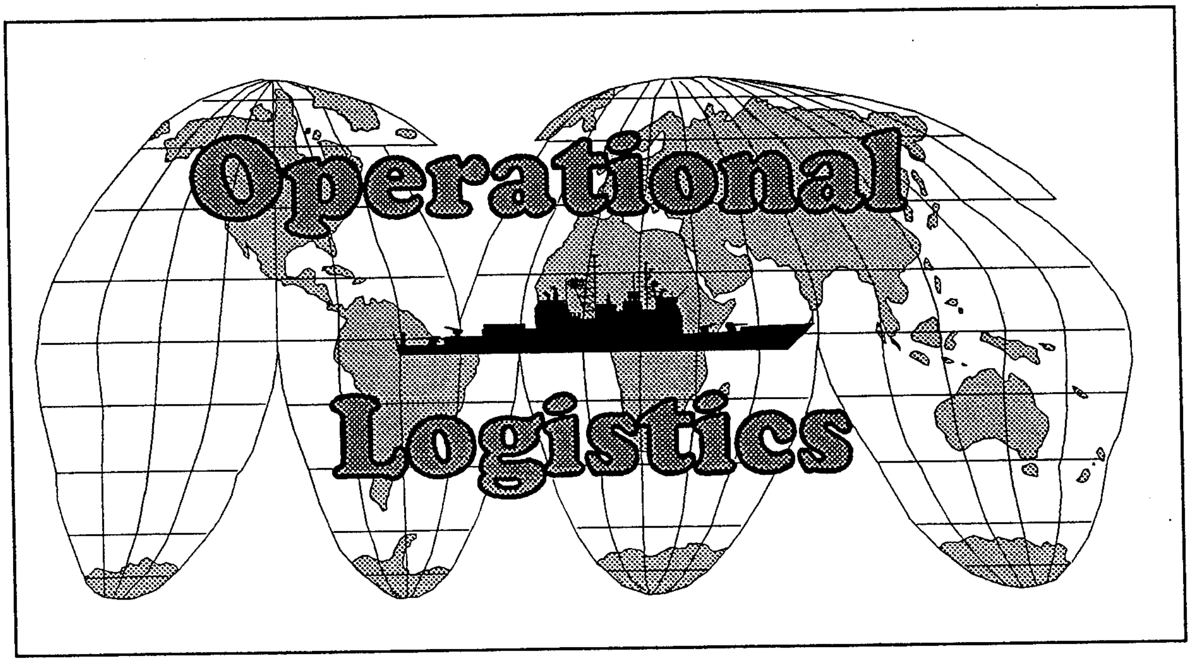
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Two integer programming models, called FLIGHT-HOURS I and II (or FH-I and FH-II), are developed to assist U.S. Pacific Fleet Air Services Planners in the allocation of air services to support basic and intermediate ship training requirements. Air services consist of aircraft towing air targets, radiating electronic signals, simulating cruise missile flight profiles, and following shipboard directions. FH-I maximizes the weighted average of fleet readiness discretely to mimic the Navy's mission rating scaling while FH-II does so continuously, reflecting percent of training requirements completed. FH-I executes slowly and produces allocations unsuitable for real-world execution. FH-II, however, quickly solves the air services allocation problem on a desktop computer, and achieves significantly higher readiness than a manually prepared allocation plan (72.1% of training requirements completed versus 61.8%).

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OPTIMAL ALLOCATION OF AIR SERVICES TO THE U.S. PACIFIC SURFACE FORCES

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ABSTRACT

Two integer programming models, called FLIGHT-HOURS I and II (or FH-I and FH-II), are developed to assist U.S. Pacific Fleet Air Services Planners in the allocation of air services to support basic and intermediate ship training requirements. Air services consist of aircraft towing air targets, radiating electronic signals, simulating cruise missile flight profiles, and following shipboard directions. FH-I maximizes the weighted average of fleet readiness discretely to mimic the Navy's mission rating scaling while FH-II does so continuously, reflecting percent of training requirements completed. FH-I executes slowly and produces allocations unsuitable for real-world execution. FH-II, however, quickly solves the air services allocation problem on a desktop computer, and achieves significantly higher readiness than a manually prepared allocation plan (72.1% of training requirements completed versus 61.8%).

THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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EXECUTIVE SUMMARY

The proliferation of cruise missiles and cruise-missile technology is a significant and growing threat to U.S. Navy ships. At the same time, however, lower real budgets are constraining air defense training, that training which is responsible for developing skills to counter cruise missiles and related airborne threats. Readiness must be maintained even as training support decreases. Therefore, optimal assignment of training is desirable. This thesis shows how to optimally allocate one component of Navy training assets, air services, in order to advance total fleet air defense readiness.

Air defense readiness (that is, completion level of tasks requiring air services) is affected by the paucity of air services and the poor allocation of these services. Aircraft flying air service missions support ships by towing air targets, radiating electronic signals, simulating cruise missile flight profiles, and following shipboard directions. Due to budget constraints, there are no longer enough Navy aircraft to provide all air services requested by ships. Contractor Air Services are provided by civilians; they satisfactorily fulfill most ship exercise requirements at reduced cost to the Navy.

Current procedures for allocating air services do not necessarily achieve the potential fleet-wide readiness possible for a given budget. Allocation plans of air services should advance total fleet readiness while ensuring ships about to deploy are combat ready, that is, in a high readiness status. Current procedures, however, unnecessarily utilize expensive, high-performance Navy aircraft and may over-allocate resources to some ships

Two integer programming models are developed here to automate allocation planning by U.S. Pacific Fleet Air Services planners in support of basic and intermediate ship exercises. The difference between the two models, FLIGHT-HOURS I and FLIGHT-HOURS II (or FH-I and FH-II), is a matter of interpretating how they maximize fleet readiness. Air defense readiness can be expressed either as a discrete cumulative threshold (M1, M2, M3,and M4, where M1 is the highest level of readiness) or percentage of training completed. Each definition suggests a separate formulation.

FH-I maximizes the weighted average of fleet readiness discretely to mimic the Navy's mission rating scaling while FH-II does so continuously, reflecting percent of training requirements completed. FH-I executes slowly and produces allocations unsuitable for real-world execution. FH-II, however, quickly solves the air services allocation problem on a desktop computer, and achieves significantly higher readiness than a manually prepared allocation plan (72.1% of training requirements completed versus 61.8%).

Improved allocation plans are critical because relief from the current budget constraints is improbable in the near future: Navy air squadron decommissionings and an overall reduction in Navy flight hours herald decreasing, rather than increasing, naval air services support. Low utilization of CAS exacerbates this situation. This thesis shows how to ensure each Navy training dollar is efficiently spent.

I. INTRODUCTION

The proliferation of cruise missiles and cruise-missile technology is a significant and growing threat to U.S. Navy ships. At the same time, however, lower real budgets are constraining air defense training, that training which is responsible for developing skills to counter cruise missiles and related airborne threats. Readiness must be maintained even as training support decreases. Therefore, optimal assignment of training is not only desirable, but mandated: "Due to fiscal and scheduling limitations, the training opportunities that are available to units of the naval surface force are limited and must be optimized" (SURFTRAMAN, 1993, p. 1-2-2). This thesis shows how to optimally allocate one component of Navy training assets, air services, in order to advance total fleet air defense readiness.

A. PROBLEM SCOPE

Air defense readiness (that is, completion level of tasks requiring air services) is affected by the paucity of air services and the poor allocation of these services. Aircraft flying air service missions support ships by towing air targets, radiating electronic signals, simulating cruise missile flight profiles, and following shipboard directions. Due to budget constraints, there are no longer enough Navy aircraft to provide all air services requested by ships:

> It is also clear that since Navy tactical aircraft cannot provide the requisite asvcs [air services], an increased reliance on CAS [Contractor Air Services] is mandated. (CNSP, 1994) ([] added by author.)

Contractor Air Services (see Figure 1 for definition of this and related lexicon) are provided by civilians; they satisfactorily fulfill most ship exercise requirements at reduced cost to the Navy.

Improved allocation plans are critical because relief from current budget constraints is improbable in the near future: Navy air squadron decommissionings and an overall reduction in Navy flight hours combined with low utilization of CAS herald decreasing, rather than increasing, air services support. Twenty-four squadron decommissionings, eighteen in the Pacific region alone, are slated for Fiscal Year 1995 and the Fleet Support portion of the Navy Flying Hour Program (which funds fuel costs for all Navy aircraft) is only 85% funded in the Five-Year Defense Plan (Comptroller of the Navy, 1994).

Judicious use of budget dollars is critical for maintaining high air defense readiness in the Navy. Anti-Air Warfare (AAW), the largest air defense warfare area, is especially sensitive to air services availability: Air services are required for twenty-three of the thirty basic and intermediate AAW training objectives. Thus, significantly lower AAW readiness results when air services availability is low. Consequently, future allocation plans should ensure the Navy receives the highest level of air defense readiness for its money.

B. BACKGROUND AND DEFINITION OF TERMS

Once commissioned, ships are assigned to a specific Fleet and enter a continuous regime of maintenance, training, and deployments (Figure 2). Ships joining the U.S.

The Navy term...	Known as...	What it means...
Air Defense Training		A warfare area defined here as consisting of all exercises requiring air services. The largest subset of air defense is Anti-Air Warfare.
Air Services	ASVCS	Air services are aircraft missions flown in support of ship training. Missions include towing air targets (TOW), emitting electronic signals (EW), and responding to ship commands (AIC).
Anti-Air Warfare	AAW	Anti-Air Warfare is the Navy concentration of personnel and equipment to counter threats in the air, including aircraft and missiles.
Commander Naval Surface Forces Atlantic, Commander Naval Surface Forces Pacific	CNSL, CNSP	The Navy commanders responsible for ensuring that deploying ships are combat ready. They are charged with scheduling and allocating training resources, such as air services and training ammunition allowances.
Contractor Air Services	CAS	Air services provided by civilians flying private aircraft, usually modified Lear or Gulfstream jets.
Event		The basic scheduling unit used to assign ships tasks during a specific time period. Ships may conduct no exercises, or many, during an event.
Exercise		A training task tailored to a warfare area, with specific objectives and requirements such as air services.
Mission rating	M-rating	The most widely used measure of combat readiness for ships, primary mission areas, and exercises.
Primary Mission Area	PMA	Major warfare areas such as Anti-Air, Anti-Surface, Anti-Submarine, and Electronic Warfare, Mobility, and Communications. Each requires numerous exercises tailored to build proficiency in that warfare area.
Surface Force Training Manual	SURFTRAMAN or STM	CNSL/CNSP Instruction 3502.2A, 1993, governing ship training requirements and reporting procedures.

Figure 1. Navy terminology is unique and potentially confusing. These terms will be used throughout this thesis.

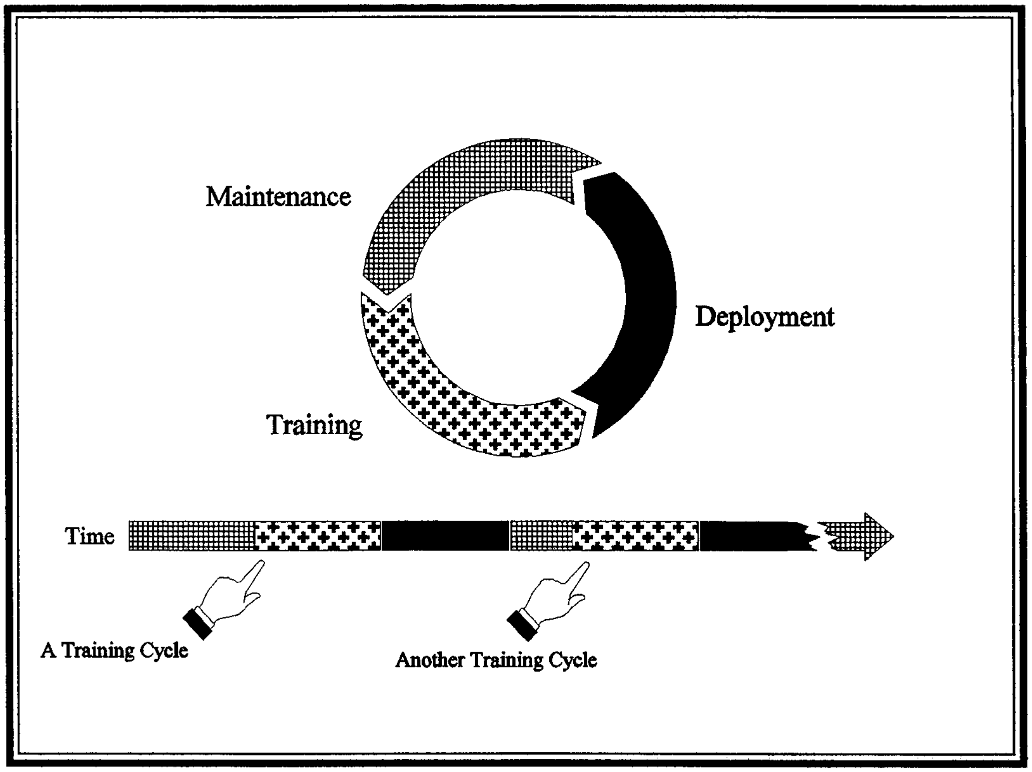

Figure 2. Ships conduct a continuous sequence of maintenance (3 to 6 months), training (6 to 9 months), and deployment (6 months) periods. A training cycle is a specific training period during which the ship must complete a training syllabus in preparation for deployment.

Pacific Fleet are assigned to one of its component numbered fleets, the Third, Fifth, or Seventh Fleet, for operational control. Ships normally rotate from Third Fleet for operations near their respective home ports to Fifth Fleet for operations in the Persian Gulf, or to Seventh Fleet for operations in the Western Pacific and Indian Oceans. The time spent in Third Fleet is primarily devoted to maintenance, training, and certification tasks while preparing for another operational assignment (a "deployment") to the Fifth or Seventh Fleet. Significant maintenance periods last from as few as three months to more than a year. A ship then spends six to nine months preparing for a six-month deployment. For purposes of this paper, the time that a ship spends preparing for deployment is the "training period." A "training cycle" is a specific instance of the recurrent training period.

The requirements of a training cycle are contingent upon the complexity of the maintenance phase—more training is required after a long maintenance period.

Ships are divided into "types" by their main mission: Guided Missile Cruiser, Guided Missile Destroyer, Destroyer, Oiler, Amphibious Assault, etc. Types are further subdivided into "classes," consisting of one or more ships. For example, ARLEIGH BURKE and KIDD are two classes of Guided Missile Destroyer. Each class has a set training syllabus consisting of specific tasks that must be completed (SURFTRAMAN, Appendix A, 1993); degree of completion is the major indicator of ship readiness.

The training syllabus is divided into "Primary Mission Areas" (PMAs) such as Anti-Air Warfare, Anti-Surface Warfare, Anti-Submarine Warfare, Electronic Warfare, Communications, Mobility, etc. Training for each PMA consists of numerous "exercises." A class of ship may be required to complete all, some, or no exercises in a given PMA. Air defense is defined here as a warfare area consisting of all exercises requiring air services, drawn from existing PMA's.

Exercises are tasks with specific support requirements, air services for example, and with training objectives within a given PMA. There are three different types of air services: target towing (TOW), radiating electronic signals (EW), and following shipboard directions (AIC). Each exercise is categorized as "Basic," "Intermediate," or "Advanced," and further differentiated as "Non-repetitive" or "Repetitive." For example, exercise AAW-21-SF is a basic, non-repetitive exercise which requires the firing of the ship's Close-In Weapon System against an air-towed target for the purpose of building basic AAW skills in ship self-defense.

"Readiness" is the measure of a ship's ability to conduct combat operations as a whole, or within a specific PMA. A ship's overall readiness is dependent upon readiness in assigned PMAs. Readiness level in a PMA is a function of the degree of training syllabus completion, active exercise caps (indicating an uncompleted critical exercise), personnel shortages, and equipment breakages for that PMA.

This thesis is concerned with allocating air services support for basic and intermediate air defense exercises among all ships in training cycles. Advanced exercises requiring air services are normally completed during Fleet Exercises prior to deployment. They involve carrier battle groups, U.S. Air Force, Air National Guard, Marine Corps units and numerous other organizations that provide air services during Fleet Exercises. As a result, air services allocations for advanced exercises are beyond the scope of this thesis.

C. TRAINING READINESS AND MEASURES

Ships are required to deploy "combat ready," that is, in a high readiness status. The Navy readiness factor is called "mission rating," or "M-rating." Outside of personnel and material limitations, readiness within a PMA (for example, air defense) is a function of training syllabus fulfillment expressed either as a discrete cumulative threshold or percentage. Table 1 shows M-rating designations, corresponding percent of training completed, and meanings (maximum readiness is denoted with an M1 mission rating and minimum readiness with M4).

TABLE 1
READINESS INDICATORS

Readiness	Mission Rating	% Training Completed
Combat Ready	M1	0.850-1.000
Mostly Ready	M2	0.700-0.849
Partially Ready	M3	0.550-0.699
Not Ready	M4	0.000-0.549

A ship's maintenance period can significantly influence the syllabus of its upcoming training cycle. Post-deployment maintenance periods can be divided into two groups, those typically lasting from three to six months and those lasting more than six months. Ship readiness is not decreased much by a short maintenance period, but is severely degraded by long ones during which personnel turnover is high and new equipment is installed: "Exercises are 'zeroed' (set to M4) upon start of overhaul or major maintenance period of six months or greater" (SURFTRAMAN, 1993, p. 6-2-3). Thus, a busy training cycle results from a long maintenance period.

D. PROBLEM APPROACH

Commander, Naval Surface Forces Pacific (CNSP) identified air defense readiness as a significant problem in 1994 (CNSP, 1994). A review of future resources available indicated that no fiscal relief could be expected. The review indicated that readiness can be maintained only by utilizing less expensive air services providers or increasing the efficiency of the current allocation process. The review noted that CAS is widely and successfully used by the Air Force under the Department of Defense Contracted Training Flight Services program, for which the Navy is an eligible participant. The review also pointed to the Navy's own success with CAS in San Diego, California. The review focused on the economic benefits of CAS, but did not suggest any method for increasing the efficiency of the current allocation process. This thesis demonstrates a method that can increase the current system's efficiency.

This thesis shows how to optimize, in terms of fleet air defense readiness, allocation plans supporting basic and intermediate exercises. The measure of effectiveness, ship air defense readiness as shown in Table 1, can be mathematically represented either discretely, mirroring the Navy's M-rating, or as a percentage of air defense exercises completed. Thus, ship readiness is expressed discretely, one through four, and continuously, zero to one. Further, each training task can be considered completed or not completed, and, therefore, mathematically represented as a binary variable. Linear relationships adequately represent budget allocations and other limitations on resources and decisions. Consequently, mathematical programming (either as a pure 0-1 integer program or as a mixed integer program) can be employed to optimally solve the air defense readiness problem.

E. THESIS OVERVIEW

Chapter II discusses the current procedures used in developing air services allocation plans for the U.S. Pacific Fleet. An illustrative example is presented. Chapter III examines two measures of readiness applicable to air defense. Each measure suggests a corresponding mathematical program for optimally allocating air services. Both models are then developed. Chapter IV relates the computational experience of the models and compares them to manual air services planners. Finally, Chapter V presents conclusions and recommendations for improving fleet air defense readiness.

II. CURRENT PROCEDURES FOR ALLOCATING AIR SERVICES

Current procedures for allocating air services do not necessarily achieve the potential fleet-wide readiness possible for a given budget. Allocation plans should advance total fleet readiness while ensuring ships about to deploy are combat ready. Current procedures, however, unnecessarily utilize expensive, high-performance Navy aircraft and may over-allocate resources to some ships. This chapter describes current procedures for allocating air services and points out where these procedures are ineffective. Current exercise scheduling procedures are described first, however, because air services are allocated to a predetermined exercise schedule.

A. SCHEDULING SHIP TRAINING EXERCISES

The allocation plan of air services (hereafter called the "allocation plan") begins with ship schedules of events that often include exercises, some requiring air services. A complete description of the planning and scheduling process is described in Wing, 1986, and summarized here.

The short-range ship employment schedule is composed of four quarters: The current operating quarter and the first, second, and third "out quarters." Allocation plans are formulated to support exercises during the first out quarter, commonly called the "planning quarter." Each ship independently composes its own tentative schedule for the planning quarter, which may or may not include events requiring air services. Each ship knows precisely its air service needs and time constraints. When attempting to

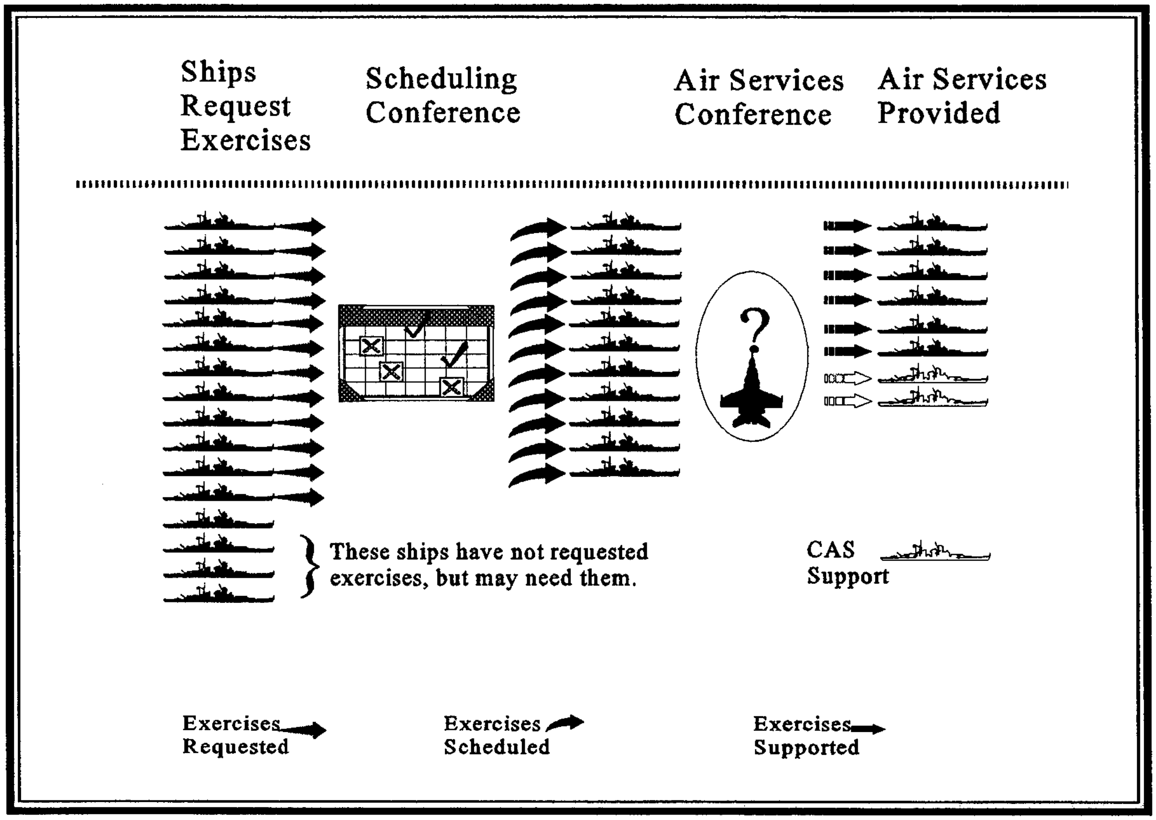

Figure 3. Ships independently request exercises, many involving air services. Most requested exercises are scheduled, though rarely during the requested time period. At the air services conference, air service planners face many challenges scheduling support for exercises: Constrained resources, conflicting schedules between ships and supporting air squadrons, and conference attendees. Planners rely upon experience and judgment to create the best possible allocation plan, but the small number of available Navy aircraft means that many requests will not be filled even after CAS support is assigned.

schedule itself, the ship does not consider the needs of other ships. Consequently, total demand for air services is subject to wide variation from quarter to quarter that requires flexibility from supporting commands and CAS as they allocate resources to the competing ships.

After proposed schedules are submitted, a scheduling conference is convened at the Fleet level to resolve conflicts. This conference is attended by ship representatives as well as all supporting commands. It lasts nearly a week and produces a detailed schedule of future events, many requiring air services. Most requested exercises are scheduled.

Ships then generate an air services request that is sent to the air services conference for allocation of aircraft support.

B. ALLOCATING AIR SERVICES

The allocation of supporting Navy aircraft, with their own schedules, and CAS is more problematic than the scheduling of the exercises. An allocation plan that promotes fleet air defense readiness should examine, at least implicitly, all possible allocations and choose the one that best advances total fleet air defense readiness. Currently, an air services conference is held in order to review requests from ships for support of scheduled exercises, and to allocate resources to support the requests. Ships not requesting support are not considered. The final product of the conference is the air services allocation plan.

Planners face numerous other challenges in developing an allocation plan. There are over one hundred ships, possible provider (Navy and CAS) constraints for each type of service (EW, TOW, or AIC), budget limitations (Navy and CAS), and aircraft shortfalls. In practice, it is not possible to manually produce an allocation plan in the limited time available with confidence that a better plan has not been overlooked. Consequently, planners strive to create feasible, rather than optimal, allocation plans. The current process is devoid of computer assistance, relies heavily upon rules-of-thumb, and is manpower-intensive.

When allocating resources under time pressure, air services planners (hereafter called the "planners") resort to experience and heuristics. They focus on satisfying air services requests but do not attempt to optimize total fleet air defense readiness. Navy aircraft have their own schedules and will only be available for ship support during certain time periods. Representation at the air services conference can help a ship receive services—"loud" ships receive services under the aegis of supporting the fleet while others receive less or none. A ship requiring basic level training may have its events descheduled at the scheduling conference, or, more likely, unfulfilled at the air services conference. This is especially true in the Middle and Western Pacific.

Ships preparing for immediate (less than thirty days) or near-term (thirty to ninety days) deployments will always receive the highest priority (Figure 4) since they are required to deploy combat ready, and no further air services conferences will be held before their deployment.

"Non-deployers," those ships more than ninety days from deployment, are typically beginning or in the midst of their training cycle. Ships more than ninety but less than 180 days from deployment constitute the largest user group of air services. They all receive the same priority according to Figure 4. However, there are not enough assets to fill all requests from this group. In practice, allocations are usually distributed among easily paired combinations of Navy ships and aircraft.

Ships more than 180 days from deployment are typically just beginning their training cycle after a maintenance period. These ships require few air services since the training emphasis is on ship safety: Damage control, seamanship, navigation, first aid, engineering, combat simulation and watch standing.

Most air defense exercises require dedicated services. That is, aircraft can only provide air services to a single ship at a time. Exercises involving electronic signal

Air Services Conference Priority List

1	Deploying within 30 days
2A	Deploying within 31-90 days (mutual use)
2B	Deploying within 31-90 days (exclusive use)
2C	Certifications
3A	School house requirements (mutual use)
3B	School house requirements (exclusive use)
4A	Deploying 91-180 days (mutual use)
4B	Deploying 91-180 days (exclusive use)
5A	Recurrent training (mutual use)
5B	Recurrent training (exclusive use)

Figure 4. Air services planners use this priority list when allocating air services to fill support requests with Navy or CAS aircraft available during the quarter (CNSP, 1994).

emissions are sometimes provided to several ships at once, but this is difficult to coordinate with the ships. As a result, air services are normally dedicated to one ship for the completion of one exercise.

The current allocation system is reactive rather than proactive, focusing on filling requests rather than overall air defense readiness. It is also laborious and certainly does not produce an optimal allocation plan, nor best advance fleet air defense readiness. It is inefficient due to time constraints, schedule conflicts between Navy aircraft and ships, reliance upon expensive Navy aircraft and lack of available Navy aircraft in parts of the Pacific region.

TABLE 2
ILLUSTRATIVE ALLOCATION PLAN

Ship	Deploys (days)	Exercises Requested	Exercises Supported	Reason	Ship	Deploys (days)	Exercises Requested	Exercises Supported	Reason
DD972	<30	1	1	Priority 1	DD984	>90	9	0+3 CAS	Priority 4
DD976	<30	7	4+3 CAS	Priority 1	FFG23R	>90	4	1	No A/C
CG57	30-90	3	3	Priority 2	FFG25R	>90	0	0	No Request
DDG994	30-90	4	3+1 CAS	Priority 2	FFG27R	>90	2	0	No A/C
DD986	30-90	11	5+6 CAS	Priority 2	FFG30	>90	10	1+1 CAS	Priority 4
FFG51	30-90	4	4	Priority 2	FFG33	>90	4	0+1 CAS	Priority 4
AOE2	30-90	5	5	Priority 2	FFG46	>90	7	3	Priority 4
LPD6	30-90	1	1	Priority 2	FFG57	>90	4	1	Priority 4
LPD9	30-90	0	0	NoRequest	LSD36	>90	3	1	Priority 4
LHD2	30-90	5	5	Priority 2	LSD45	>90	3	1	Priority 4
LSD40	30-90	5	5	Priority 2	LHA3	>90	10	3	Priority 4
CG62	>90	10	3	Priority 4	LHA5	>90	10	2+1 CAS	Priority 4
CG63	>90	6	2	Priority 4	LPD8	>90	0	0	No Request
DD964	>90	0	0	No Request	LPH11	>90	3	1	Priority 4
DD965	>90	0	0	No Request	AOE1	>90	0	0	No Request
DD967	>90	6	2	Priority 4	DD985	>180	6	0	No A/C
DD973	>90	13	3	Priority 4	FFG12R	>180	0	0	No Request

Air services planners respond to requests, allocating aircraft on a priority basis (A/C is shorthand for aircraft). Note that high priority ships are well served.

C. ILLUSTRATIVE ALLOCATION PLAN

Air services conferences are classified, but an unclassified example is illustrated in Table 2. Only the total number of requests by each ship is shown, not individual exercises. The allocation plan produced uses priorities in Figure 4 and past performance of planners as relayed by CNSP (CNSP, 1995).

Allocation plans developed with current procedures share some common traits:

- Deployers receive priority support (e.g., DD972, DD976, CG57, etc.),
- there is heavy reliance on Navy aircraft , and
- allocations are made to fill requests only (e.g., DD976 versus LPD9).

Undesirable consequences of these characteristics include:

- allocations may be made to support previously completed exercises, and
- allocations may be made to combat ready ships.

In this example, a Navy budget of $955,200 and a CAS budget of $116,400 is used. There are 34 ships in the example. Two ships deploy within 30 days (the highest priority group), nine between 30 and 90 days, 21 between 90 and 180 days, and two are more than 180 days from deployment. Exercise requests range from zero to 13, with an average of 4.59 exercise requests per ship. Seven ships did not request any exercises.

Planners achieved an average air defense M-rating of 2.77, and a training syllabus completion average of 61.8%. In Chapter IV, these results are compared to those produced by optimization models to show that significant improvements are possible.

III. THE FLIGHT-HOURS MODELS

Two integer programming models are developed here to automate allocation planning in support of basic and intermediate ship exercises. The difference between the two models, FLIGHT-HOURS I and FLIGHT-HOURS II (or FH-I and FH-II), is a matter of interpreting how they maximize fleet readiness. As noted in Chapter I, readiness can be represented either discretely by M-ratings, or continuously by percent of exercises completed. Each definition suggests a separate formulation.

A. MODEL DESCRIPTIONS

Both FH-I and FH-II optimally allocate aircraft to individual ships for completion of specific exercises. These models:

Maximize	fleet air defense readiness (measured in two alternate ways),
subject to	budget limitations in dollars, and
	air services availability.

The objective functions of FH-I and FH-II improve the weighted average of air defense readiness measured by mission rating and percentage of syllabus completed, respectively. Immediate and near-term deployers need priority support, and ships are weighted to reflect this. The Navy Flying Hour Program-Fleet Support account and CAS contract values are the budget constraints for each provider. Finally, air services availability constraints, by provider, ensure that no type of air services is oversubscribed.

B. FH-I AND FH-II ASSUMPTIONS

Funding levels for Navy and CAS are assumed known. This is reasonable since the Navy funds the costs of air services through the Flying Hour Program-Fleet Support account and CAS funding levels are contractual. The Flying Hour Program-Fleet Support account covers fuel costs only. CAS contract values reflect the total obligation of the Navy.

Provider air services limitations are assumed known. Navy limitations of providing EW, TOW, or AIC services are normally provided at the air services conference while CAS limitations are contractual. For instance, one CAS contract in effect in San Diego, California, stipulates that the contractor will provide 325 hours of TOW and 3000 hours of AIC services per year.

Exercises that need to be completed during the planning quarter are assumed known for each ship. These include all exercises in the training syllabus less those completed exercises (whose qualifications will not expire during the planning quarter). Exercises scheduled in the current quarter are considered completed. This is reasonable because the majority of scheduled exercises are, or will be, completed.

We assume that supported exercises (those for which aircraft are allocated) are scheduled. This is reasonable since ships in the training cycle are underway a sufficient number of days each quarter, and most requested exercises are scheduled sometime during the quarter—though not always during the exact time period requested by the ship.

C. FH-I AND FH-II DATA REQUIREMENTS

Both FH-I and FH-II need required exercises by ship, the history of exercise completion by ship, and the type of air services required for each exercise. This data is readily available: Surface Training Manual (CNSP, 1993) details required exercises by ship class; the Navy's Status of Resources and Training System (NWP 10-1-11, Revision A, SORTS) provides exercise completion data; and the Exercise Flight Hour Requirements (CNSP, 1994) memorandum details the air services hours required for each exercise. Table 3 shows the expanded data requirements (total number of exercises required by each ship is listed rather than individual exercises).

The Exercise Flight Hour Requirements memorandum shows the time in flight hours required of each service type by exercise. Charges are levied based on hours flown and type of service rendered. The cost for a exercise can thus be calculated. An example is shown in Figure 5, with costs calculated.

Exercise Air Services Requirements And Costs

	EW	TOW	AIC	USN	CAS
AAW-11-I	0	1	2	$28,600	$10,200

Figure 5. Each exercise has specific air service requirements, measured in flight hours. This exercise requires zero hours of electronic emissions (EW), one of target towing (TOW), and two of aircraft control (AIC) services. U.S. Navy provided support costs $28,600 for fuel alone while CAS support costs only $10,200 total.

TABLE 3

FH-I AND FH-II DATA REQUIREMENTS

Ship	Deploys (days)	M-Rating	Exercises in Syllabus	Exercises Completed	Exercises to Attain M-rating All	1	2	3	Ship	Deploys	M-Rating	Exercises in Syllabus	Exercise Completed	Exercises to Attain M-rating All	1	2	3
DD972	<30	1	35	34	1				DD984	>90	3	35	23	12	7	2	
DD976	<30	2	35	28	7	2			FFG23R	>90	3	30	19	11	7	2	
CG57	30-90	1	32	31	1				FFG25R	>90	3	30	20	10	6	1	
DDG994	30-90	1	34	32	2				FFG27R	>90	4	30	13	17	13	8	4
DD986	30-90	2	35	22	13	8	3		FFG30	>90	4	33	7	26	22	17	12
FFG51	30-90	2	33	22	11	7	2		FFG33	>90	3	33	23	10	6	1	
AOE2	30-90	3	14	5	9	7	5	3	FFG46	>90	4	33	17	16	12	7	2
LPD6	30-90	3	8	5	3	2	1		FFG57	>90	4	33	15	13	10	7	4
LPD9	30-90	2	8	6	2	1			LSD36	>90	4	6	2	4	4	3	2
LHD2	30-90	3	25	15	10	7	3		LSD45	>90	4	6	0	6	6	5	4
LSD40	30-90	4	6	0	6	6	5	4	LHA3	>90	4	24	11	13	10	6	3
CG62	>90	3	32	20	12	8	3		LHA5	>90	3	24	14	10	7	3	
CG63	>90	3	32	21	11	7	2		LPD8	>90	4	8	3	5	4	3	2
DD964	>90	2	35	29	6	1			LPH11	>90	3	9	5	4	3	2	
DD965	>90	3	35	22	13	8	3		AOE1	>90	4	14	6	9	6	4	2
DD967	>90	4	35	16	19	14	9	4	DD985	>180	4	35	0	35	30	25	20
DD973	>90	2	35	9	26	21	16	11	FFG12R	>180	4	30	2	28	24	19	15

For example, DD972 (ship name) deploys within 30 days, has an M-rating of 1, and has completed 34 of 35 required exercises. DD976 also deploys within 30 days, has an M-rating of 2, has completed 28 of 35 required exercises, and must complete 2 exercises to attain an M-rating of 1.

D. MODEL FORMULATIONS

1. FLIGHT-HOURS I (FH-I)

FH-I allocates Navy and CAS aircraft to support ship exercises. A ship's resultant M-rating is evaluated based on the number of supported exercises and the ship's M-rating prior to model execution. FH-I belongs to a class of problems known as "0-1 Integer Programs (0-1 IPs)" that are generally solved by the branch-and-bound method. The complete mathematical formulation of FH-I is:

Indices

s	ship	e.g., AOE7, AOR2, ..., WMEC2
e	exercise	AAW-10-SF, ..., NCO-32-SF
a	air service type	EW, TOW, AIC
p	provider	USN, CAS
m	mission rating	1,2,3,4 (1 indicates higher readiness than 2, ...)

Induced Sets

$E(s)$ exercises e required by ship s

$E(s,a)$ exercises e required by ship s, air service a

Data

$budget_p$ budget in dollars for provider p

c_{ep} cost in dollars of exercise e supplied by provider p

h_{ea} hours of air service type a required by exercise e

r_{sm} cumulative number of exercises for ship s to complete in order to advance one mission rating m ($r_{s1} \geq r_{s2} \geq \ ...$)

u_{ap} flight hour limitations of air service a supplied by provider p

w_s weight of ship s, expressing ship priority

Decision Variables

x_{sep} binary variable that is 1 if ship s is assigned exercise e to be provided by provider p, and 0 otherwise.

y_{sm} binary variable that is 1 if ship s is attains mission rating m, and 0 otherwise.

Formulation

$$\text{Minimize} \qquad \sum_{s} \sum_{m} m w_s y_{sm} \tag{1}$$

$$\text{Subject to} \qquad \sum_{s} \sum_{e \in E(s)} c_{ep} x_{sep} \leq budget_p \qquad \forall\, p \tag{2}$$

$$\sum_{s} \sum_{e \in E(s,a)} h_{ea} x_{sep} \leq u_{ap} \qquad \forall\, a,p \tag{3}$$

$$\sum_{e \in E(s)} \sum_{p} x_{sep} \geq r_{sm} y_{sm} \qquad \forall\, s,m \tag{4}$$

$$\sum_{p} x_{sep} \leq 1 \qquad \forall\, s, e \in E(s) \tag{5}$$

$$\sum_{m} y_{sm} = 1 \qquad \forall\, s \tag{6}$$

$$x_{sep} \in \{0,1\} \qquad \forall\, s,e,p$$
$$y_{sm} \in \{0,1\} \qquad \forall\, s,m$$

Equation (1) represents the weighted average mission rating for the fleet. This is used to maximize this measure of fleet readiness. Ships are weighted to reflect ship priority. Ships deploying immediately or in the near-future receive the highest priority. The explicit use of M-rating in the objective function fosters allocation of resources to the ship with the worst (numerically highest) M-rating, and thus poorest readiness, when all other factors are equal.

The air services allocation problem has two defining resource constraints:

budget and flight hours available by provider. Equations (2) are the budget constraints that limit the costs of air services supplied by each provider, Navy and CAS. Equations (3) are multiple resource constraints and must be included here to reflect global air service type (EW, TOW, AIC) constraints that may exist by provider.

Equations (4) are fixed-charge constraints. A certain number of exercises must be assigned (x_{sep}=1) for the ship's selected M-rating (y_{sm}=1). Values for r_{sm} vary considerably depending on ship class, preceding maintenance period, and number of exercises completed or about to expire (see Table 3). These values are also cumulative, i.e., more exercises must be assigned for a ship to attain M1 than M2, M2 than M3, and M3 than M4. Since M4 is the lowest possible rating, r_{s4} is zero. As a result, allocating no exercises to any ship is always a feasible solution.

Equations (5) limit support assignments to no more than one provider per exercise. This allows for no provider assignment, indicating that exercise e will not be completed by ship s. Equations (6) force a single M-rating assignment for each ship. This triggers the fixed-charge in (4) and changes the objective function value (1).

FH-I is encouraged to assign air services to the more heavily weighted, deploying ships. FH-I also generally assigns less expensive exercises to ships, but allows for more expensive exercises if they best improve the objective function. For example, it may be more beneficial to assign a relatively expensive exercise to a ship if that one exercise increases the ship's M-rating, instead of assigning several inexpensive exercises (whose total expense is greater) to another ship for a similar gain in M-rating. Further, FH-I exploits less expensive CAS support, allowing for considerably more exercise assignments than the current, manual allocation process for a given budget.

FH-I produces an optimal allocation plan measured in terms of the discrete M-ratings. However, the resulting plan may exhibit awkward features. First, either no resources are allocated to a ship, or resources are allocated in blocks large enough to raise it a higher M-rating. For a ship that has completed few exercises, this may mean a requirement to complete over half of its training syllabus in one quarter. This may not be feasible. Second, ships attain an M1 rating at 85.0% completion of the training syllabus. Thus, they will not complete their syllabus unless resources remain from all other ships able to improve readiness. As a result, M-rating is an incomplete measure of effectiveness. Further, FH-I does not run quickly on a desktop computer. FH-I maximizes readiness based on the Navy's most widely used measure, M-rating, but fails to produce useable results.

2. FLIGHT-HOURS II (FH-II)

FH-II is a mixed integer program (MIP) that assigns exercises to ships, maximizing the weighted average of training completed. If a ship completes six of twenty exercises, say, FH-II is encouraged to make allocations to other, equally weighted, ships until they too reach thirty percent completion. FH-II runs quickly on a desktop computer and the resultant solution is executable. If desired, results can be converted to M-ratings by referring to Table 1. The FH-II solution is different than the FH-I solution, of course, since the objective function no longer explicitly maximizes M-rating.

In FH-I, discrete M-ratings in the objective function promote allocating

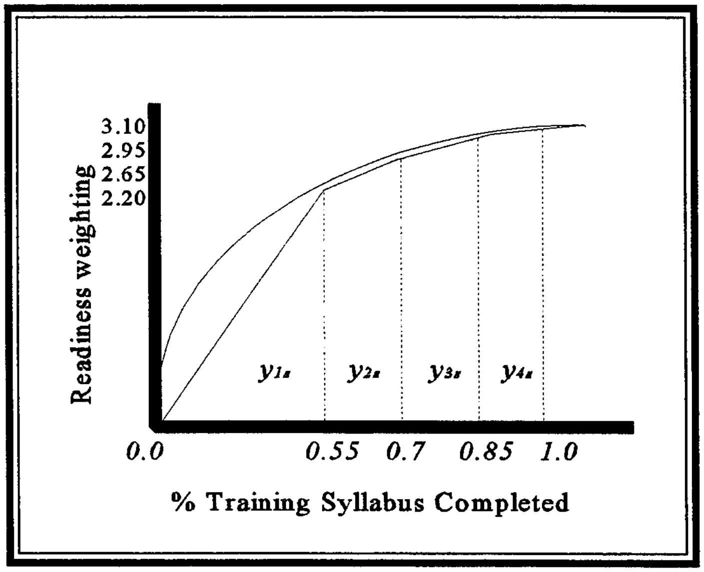

Figure 6. Readiness weighting is a function of the training syllabus completed. A concave function linearly approximated will encourage allocation to less ready ships. The approximation's slope is 4.0 for region y^1_s, and decreases to 1.0 for region y^4_s, which is analogous to using M-ratings in the objective function of a mathematical program like FH-I. Note that the breakpoints are the same as for M-ratings (see Table 1).

support to less ready ships. Here, a linear approximation of readiness, measured as a concave function of percentage of syllabus completed, serves the same purpose (Figure 6).

The complete mathematical formulation of FH-II is:

Indices

s	ship	e.g., AOE7, AOR2, ..., WMEC2
e	exercise	AAW-10-SF, ..., NCO-32-SF
a	air service type	EW, TOW, AIC
p	provider	USN, CAS
i	readiness break point	1, 2, ..., I

Induced Sets

$E(s)$ exercises e required by ship s

$E(s,a)$ exercises e required by (ship s, air service a)

Data

$budget_p$ budget in dollars for provider p

c_{ep} cost in dollars of exercise e supplied by provider p

h_{ea}	hours of air service type a required by exercise e
k_s	number of exercises ship s has already completed
r_s	total number of exercises in the training syllabus of ship s
u_{ap}	flight hour limitations of air service a supplied by provider p
w_s	weight of ship s based on priority
$frac_i$	break points of the linear approximation (e.g., 0.0, 0.55, 0.7, 0.85, 1.0)

Decision Variables

x_{sep}	binary variable which is 1 if ship s is assigned exercise e to be provided by provider p, and 0 otherwise.
y_s	continuous variable which represents the percentage of its training syllabus ship s will complete after allocation and execution
y_s^i	binary variable which is 1 if y_s takes on a value $frac_i \leq y_s \leq frac_{i+1}$, and 0 otherwise.
z_s^i	bounded continuous variable ($0 \leq z_s^i \leq 1.0$) representing the relative weight associated with a break point to y_s

Formulation

$$\text{Maximize} \qquad \sum_s w_s y_s \tag{7}$$

$$\text{Subject to} \quad \sum_s \sum_{e \in E(s)} c_{ep} x_{sep} \leq budget_p \qquad \forall\, p \tag{8}$$

$$\sum_s \sum_{e \in E(s,a)} h_{ea} x_{sep} \leq u_{ap} \qquad \forall\, a,p \tag{9}$$

$$\sum_p x_{sep} \leq 1 \qquad \forall\, s, e \in E(s) \tag{10}$$

$$\frac{k_s + \sum_{e \in E(s)} \sum_p x_{sep}}{r_s} = y_s \qquad \forall\, s \tag{11}$$

$$\sum_i frac_i z_s^i = y_s \qquad \forall\, s \tag{12}$$

$$z_s^1 \leq y_s^1 \qquad \forall\, s \tag{13}$$

$$z_s^{i\ 1} \leq y_s^i + y_s^{i\ 1} \qquad \forall\, s, i \tag{14}$$

$$z_s^{I} \leq y_s^{I\,1} \qquad \forall\, s \tag{15}$$

$$\sum_i z_s^{\,i} = 1 \qquad \forall\, s \tag{16}$$

$$\sum_i y_s^{\,i} = 1 \qquad \forall\, s \tag{17}$$

$$\begin{array}{ll} x_{sep} \in \{0,1\} & \forall\, s,e,p \\ y_s^{\,i} \in \{0,1\} & \forall s,i \\ y_s \geq 0 & \forall\, s \\ z_s^{\,i} \geq 0 & \forall\, s,i \end{array}$$

FH-II assigns specific exercises to each ship, but proportionately distributes available air services to equally weighted ships. Equation (7) represents the weighted average number of exercises completed, which maximizes the weighted average of training completed. Ships are again weighted to reflect actual allocation priorities to immediate and near-term deployers.

As before, equations (8) are again provider budget constraints and equations (9) reflect provider EW, TOW, and AIC availability constraints. Equations (10) ensure only one provider supports an exercise.

Equations (11) indicate the proportion of training to be completed. For a particular ship, this is the actual percentage of its training syllabus completed after all allocations are made and the plan executed. Equations (12) link (11) to the objective function. For a particular ship *s*, an exercise assignment (x_{sep} =1) alters (11) and (12), in turn changing the objective function (7).

Equations (13) through (17) define the linear concave approximation and the relationship between y_s^i and z_s^i (e.g., Winston, 1991, p. 462). For a given ship s, equations (17) allow only a single y_s^i to equal one. The adjacent weights, z_s^i and z_s^{i+1}, associated with the two defining break points for y_s^i=1, may be positive and all other z_s^i values must be zero. As a result, z_s^i and z_s^{i+1} initiate a change in value for y_s in (12). The objective function changes accordingly.

FH-II maintains readiness parity among equally weighted ships. It equitably allocates resources according to relative need. Need is based on the number of exercises uncompleted in relation to the size of the ship's syllabus. Further, FH-II does not overburden ships like FH-I. Consequently, FH-II produces executable allocation plans.

IV. IMPLEMENTATION AND RESULTS

FH-I and FH-II are implemented in the General Algebraic Modeling System (GAMS) (Brooke, Kendrick, and Meeraus, 1992). FH-I is solved using XA (Sunset Software Technology, 1993) and CPLEX (CPLEX Optimization, Inc., 1994) while FH-II is solved using XA only. Results from FH-I and FH-II are compared to results from manual planners. The example of Chapter II is used as a basis for comparison. Additionally, use of FH-I and FH-II in budget planning is addressed. Both FH-I and FH-II were developed and tested on a personal computer with an Advanced Micro Devices AMD486DX4 CPU operating at 100 MHZ, with further testing of FH-I on an IBM RS/6000 mini-computer.

A. COMPARISON OF FH-I AND FH-II WITH MANUALLY PRODUCED RESULTS

Both FH-I and FH-II achieve higher readiness than manual planners. The comparisons are based on the example in Chapter II (see Table 2). Unlimited utilization of CAS will obviously result in higher air defense readiness since more exercises can be supported for the same budget level. Therefore, both FH-I and FH-II are run with the same budget composition as the example ($955,200 for Navy provided services and $116,400 for CAS) to isolate the contribution of optimization. Manual planners obtained an average mission rating of 2.77 and an average training syllabus completion of 61.8%. The appendix details the results of the three allocation plans (manual planners, FH-I, FH-

II) for each ship. Table 4 shows a summary of the comparison trials.

FH-I achieves an average readiness of 1.56 compared to the 2.77 performance of the planners. That is, each ship achieves a readiness level that is, on average, one M-rating higher than that achieved by manual planners. However, FH-I did not run successfully on a desktop computer using the XA solver: No integer solution is found after 2.6 hours of CPU time and one million iterations. The CPLEX solver running on an IBM RS/6000 mini-computer does successfully solve the problem. The solution obtained is guaranteed to be within 5% of optimality.

TABLE 4
COMPARISON SUMMARY

	Manual Planners	FH-I	FH-II
Fleet Readiness			
Average Mission Rating	2.77	1.56	1.76
Average Fraction of Syllabus Completed	0.618	0.773	0.721
Computing Resource			
Computer	None	RS/6000	486DX4-100
Solver	None	CPLEX	XA
Resource Usage (CPU Min:Sec)			
Model Generation	N/A	0:01	0:01
Solution Time	N/A	4:01	1:09
Total Time	approx. 1 week	4:19	1:10

FH-II achieves an average readiness of 72.1% compared to 61.8% obtained by manual planners. The solution listed is guaranteed to be within 5% of optimality. The syllabus completion fraction for FH-II is smaller than that for FH-I, but this just results from FH-II insisting on parity: FH-II must fill some expensive requirements to do this while the requirement does not exist in FH-I. FH-II runs well on a desktop computer using the XA solver and produces realistic allocation plans. It is suitable for use by planners to aid in formulating allocation plans.

B. COMPUTATIONAL EXPERIENCE

1. Computational Experience with FH-I

Using the example of Chapter II as a starting point, computational results are collected for various budget compositions. The total budget is $1,071,600. First, a baseline run (as described in the previous section) is made with the same budget composition as the manual planners ($955,200 for Navy provided services and $116,400 for CAS). Second, five runs are made with a CAS budget of $200,000 that increases $200,000 each iteration; the Navy portion is the balance of the total budget. GAMS generates models with 909 (906 discrete) variables, 564 constraints, and 5829 non-zero elements in approximately 1.35 seconds for each of the six trials. A relative termination criteria of 5% is used, meaning that if a solution is obtained, it must provably be within 5% of optimality, i.e., have a "relative optimality gap" of no more than 5%.

Results using a desktop computer and the XA solver are unsatisfactory. All six trials terminate at a designated "iteration" limit (limit on the number of linear programming pivots) of 120,000. In three of the six trials, no integer solution is found before the solver is interrupted (after 11.4 to 21.3 minutes). None of the six trials is solved to within 5% of optimality. An attempt to solve the baseline run to within 5% of optimality using an iteration limit of one million was made. The iteration limit was violated after 2.6 hours with a relative gap of 15.6% remaining. Consequently, FH-I is not suitable for execution on a desktop computer using the XA solver.

The CPLEX solver, run on an IBM RS/6000 mini-computer, shows improved performance. These computational results are reported in Table 5. All solutions reported are within 5% of optimality. An attempt to reach optimality for the baseline run using an iteration limit of 400,000 results in an average M-rating of 1.56. This is the same readiness result achieved when solving to within 5% of optimality as reported in the previous section. The solution is within 0.7% of optimality and is achieved in 13 minutes.

TABLE 5
FH-I COMPUTATIONAL RESULTS
(IBM RS/6000 MINI-COMPUTER AND CPLEX SOLVER)

CAS Budget	$116,400	$200,000	$400,000	$600,000	$800,000	$1,000,000
Fleet Readiness						
Average M-rating (a lower numerical value indicates higher readiness)	1.56	1.53	1.41	1.26	1.21	1.18
Resource Usage (CPU Min:Sec)						
Model Generation	0:01	0:01	0:01	0:01	0:01	0:01
Solution Time	4:18	5:05	1:18	0:25	0:30	0:30
Total Time	4:19	5:06	1:19	0:26	0:31	0:31

2. Computational Experience with FH-II

Computational experience with FH-II on a 486DX4-100 desktop computer is good. The set of test cases described in the previous section was run with FH-II for comparison. GAMS generates models with 1113 (906 discrete) variables, 700 constraints, and 4261 non-zero elements in about one second for each trial. Solution times are quick, ranging from 31 seconds to 4.3 minutes. Computational results are shown in Table 6.

Results reported are all within 5% of optimality. For the baseline run, a relative optimality gap of 4.7% remains after 1.15 minutes. An attempt to reach optimality for the baseline run results in a relative gap of 4.2% after 5.35 hours. The run terminates after exceeding one million iterations.

TABLE 6
FH-II COMPUTATIONAL RESULTS
(486DX4-100 DESKTOP COMPUTER AND XA SOLVER)

CAS Budget	$116,400	$200,000	$400,000	$600,000	$800,000	$1,000,000
Fleet Readiness						
Average Fraction of Syllabus Completed	0.721	0.807	0.821	0.839	0.842	0.880
Resource Usage (CPU Min:Sec)						
Model Generation	0:01	0:01	0:01	0:01	0:01	0:01
Solution Time	1:09	1:25	1:23	1:08	1:16	1:15
Total Time	1:10	1:26	1:24	1:09	1:17	1:16

C. FH-II IN BUDGET PLANNING

FH-II can be used to assist in planning and projecting budget requirements for air services, and for evaluating the resulting air defense readiness. (FH-I could be used if it could be modified to be more computationally efficient and to produce more executable allocations.) That is, "readiness curves," as a function of Navy and CAS budget levels, can be created with repeated model runs. Budget requests could then be based on well-defined

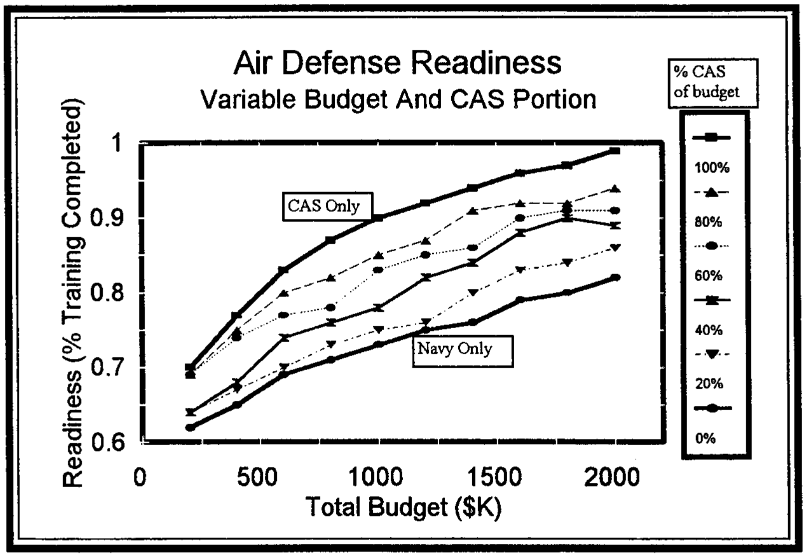

Figure 7. FH-II can aid in planning and budgeting, evaluating budget composition and indicating the best resulting air defense readiness possible. These curves are generated using the example from Chapter II.

ship requirements with an indication of the resultant air defense readiness. Figure 7 illustrates a set of readiness curves for budgets ranging from $200,000 to $2,000,000. The percentage of the budget devoted to CAS ranges from 0% to 100%. The curves are based on model runs using the data from Chapter II. If FH-II were used in this way in practice, the data should be modified to account for repetitive exercises and exercises expiring during the fiscal year; they were not accounted for here.

V. CONCLUSIONS

The optimal solutions of both FH-I and FH-II achieve improved fleetwide, air defense readiness in comparison to manual planners. Both models allocate air services to ships in an equitable manner while advancing a fleet-wide perspective of air defense readiness. The results are clear: Any allocation policy that consistently strives for maximum air defense readiness is superior to the current system.

FH-II is the best choice to aid air services planners in developing allocation plans for basic and intermediate exercises. It runs quickly on a desktop computer using the XA solver and produces executable allocation plans. FH-I does not run as quickly and, more importantly, does not produce realistic allocation plans.

FH-I and FH-II show that requirements can better be filled when optimally allocated. Optimization of air services or greater use of CAS, or both, will either (a) fulfill most or all air services, or (b) generate a surplus supply of air services. If a surplus is generated, the Navy could either decrease their budget outlays for air services, or maintain the budget and increase Navy flying hours in non-support roles. The extra hours can be spent in valuable combat training or advanced exercises. In contrast, the current system requires Navy pilots to fly mundane support missions of limited combat value.

FH-I and FH-II are not finished products. This thesis is a "proof of concept" that demonstrates quantifiable benefits in readiness by utilizing optimal allocations of air services. More importantly, FH-I and FH-II demonstrate that (a) the air services allocation problem for basic and intermediate training is well-defined, (b) required data exist and are easily obtained, (c) allocation rules and priorities can be mathematically represented, and (d) near-optimal solutions are obtainable.

The process of providing air services to the Fleet is expensive. The greatest contribution of this thesis may be to indicate that clear objectives lead to better allocation plans, and that expanded use of CAS is in the Navy's better interest. FH-I and FH-II provide the basis for continued analysis of the air services allocation problem, and demonstrate that mathematical programming can help ensure each training dollar is efficiently spent.

APPENDIX. DETAILED SHIP READINESS RESULTS

This appendix lists each ship from the example in Chapter II and its final readiness level based on the three allocation plans developed (planners, FLIGHT-HOURS I, and FLIGHT-HOURS II).

Ship Data			Air Services Planners		FH-I	FH-II
Ship	Deploys (days)	Starting M-rating	Final M-rating	Fraction of Exercises Completed	Final M-rating	Fraction of Exercises Completed
DD972	<30	1	1	1.00	1	0.97
DD976	<30	2	1	1.00	1	0.86
CG57	30-90	1	1	1.00	1	0.97
DDG994	30-90	1	1	1.00	1	0.94
DD986	30-90	2	1	0.94	1	0.71
FFG51	30-90	2	2	0.78	1	0.73
AOE2	30-90	3	2	0.72	1	0.79
LPD6	30-90	3	2	0.75	1	0.88
LPD9	30-90	2	2	0.75	1	0.75
LHD2	30-90	3	2	0.80	1	0.76
LSD40	30-90	4	2	0.83	1	0.83
CG62	>90	3	2	0.75	1	0.72
CG63	>90	3	2	0.72	2	0.72
DD964	>90	2	2	0.83	1	0.86
DD965	>90	3	4	0.63	1	0.71
DD967	>90	4	4	0.51	2	0.71
DD973	>90	4	4	0.37	4	0.51
DD984	>90	3	2	0.74	1	0.71

Ship Data			Air Services Planners		FH-I	FH-II
Ship	Deploys (days)	Starting M-Rating	Final M-rating	Fraction of Exercises Completed	Final M-rating	Fraction of Exercises Completed
FFG23R	>90	3	3	0.67	1	0.70
FFG25R	>90	3	3	0.67	1	0.87
FFG27R	>90	4	4	0.57	2	0.53
FFG30	>90	4	4	0.27	4	0.52
FFG33	>90	3	2	0.73	1	0.73
FFG46	>90	4	3	0.60	3	0.73
FFG57	>90	4	4	0.49	1	0.73
LSD36	>90	4	4	0.50	1	0.83
LSD45	>90	4	4	0.17	1	0.83
LHA3	>90	4	3	0.58	2	0.71
LHA5	>90	3	3	0.13	2	0.71
LPD8	>90	4	4	0.38	1	0.75
LPH11	>90	3	4	0.66	1	0.89
AOE1	>90	4	4	0.43	1	0.79
DD985	>180	4	4	0.00	4	0.00
FFG12R	>180	4	4	0.07	4	0.07

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